SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 151, NUMBER 5
(Publication 4694)

Roebling Fund

PRECIPITATION IN FIVE CONTINENTS

By
C. G. ABBOT, D.Sc.
RESEARCH ASSOCIATE, SMITHSONIAN INSTITUTION

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION PRESS
MAY 31, 1967

PORT CITY PRESS, INC.
BALTIMORE, MD., U. S. A.

PRECIPITATION IN FIVE CONTINENTS

By C. G. ABBOT, D.Sc.
Research Associate, Smithsonian Institution

TWENTY-FOUR YEARS AGO I reported a family of regular harmonic periods, both in solar variation and, with identical periods, also implicit in weather records.[1] Twenty-seven members of this family in weather are of sufficient amplitude to produce by their combined simultaneous influence at least 60 percent control of precipitation.

In 1960 the Smithsonian Institution published my paper *A Long-Range Forecast of United States Precipitation*."[2] That paper tabulated precipitation for 32 cities in monthly and 4-monthly intervals from 1950 through 1967. Besides its usual free distribution of 1,500 copies, the Smithsonian sold over 5,000 copies.

The purposes of the present paper are:

(a) To acquaint foreign meteorologists with our results on solar radiation and weather.

(b) To publish forecasts for 23 cities, 1965 through 1970, and also to compare the forecasts from 1950 through 1964 with observed precipitation. The forecasts will be based exclusively on the meteorological records, 1870-1949.

(c) To indicate to what extent such forecasts are devalued by the severe bombing of England, Germany, and Japan in 1944-1945, and by the far greater hydrogen bomb explosions by the United States and the U.S.S.R. around 1950 and about 1960.

HISTORICAL SUMMARY

A succinct history of the entire research, completely illustrated and documented,[3] was published by the Smithsonian (Publication 4545)

---

[1] Published as Chapter VII, vol. 2, 2d edition, 1943, Smithsonian Scientific Series. Republished by Smithsonian Institution separately, 1962, as Publication 4505.

[2] Smithsonian Miscellaneous Collections, vol. 139, No. 9, Publication 4390, 1960.

[3] *Solar Variation and Weather,* Smithsonian Miscellaneous Collections, vol. 146, No. 3, Publication 4545, 1963.

SMITHSONIAN MISCELLANEOUS COLLECTIONS, VOL. 151, NO. 5

in 1963. References to the original sources are given in the Appendix to Publication 4545. The *Journal of Solar Energy and Engineering* in 1957 and 1958 published the essentials and details of procedure found necessary to make long-range weather predictions. (See "Supplementary References," Smithsonian Publication 4545, page 67). Certain modifications of these directions will be given below. Another paper worth attention is *Solar Variation, a Leading Weather Element.*[4] Finally, Publications 4656 [5] and 4659,[6] 1966, are of special interest.

It is well nigh certain that a theoretical link connects periodic solar variation with weather. Because the harmonic family of 27 members related to 273 months occurs with identical periods in both. Thus far, no meteorologist, or mathematician skilled in hydrodynamics, has sought this link. I, indeed, have made a suggestion toward it. (Smithsonian Publication 4135, p. 3). Generally the principal features of changes which result from periodic solar variation occur *simultaneously* in graphs comparing forecasts with observation. Occasionally, however, large *shifts* of the order of 3 to 5 months occur between the dates predicted and effects observed.

To demonstrate that 27 regular weather periods exist, hitherto officially unrecognized, but of sufficient amplitude to mainly control precipitation and temperature, I will repeat below some proofs given in Smithsonian Publication 4545, and add new ones from the present studies. It will not be necessary in these weather studies to consider variations in solar radiation, because (apart from a recognition of the well-known sunspot cycle of $11\frac{1}{3}$ years) *all predictions of weather* to be given below are *exclusively* based on, and computed solely from, *World Weather Records,* volumes I, II, III, IV, published by the Smithsonian Institution and the U.S. Weather Bureau. The weather records to be used in predicting all lie within the interval 1870-1949. Records of 1950-1965, used below for comparison with predictions, have been furnished mainly by Dr. H. Landsberg, climatologist of the U.S. Weather Bureau, and partly by my own correspondence with friends in several countries.

The *phases,* but not the lengths, of the 27 weather periods used

---

[4] Smithsonian Miscellaneous Collections, vol. 122, No. 4, Publication 4135, 1953.

[5] *An Account of the Astrophysical Observatory of the Smithsonian Institution, 1904-1953,* Smithsonian Miscellaneous Collections, vol. 148, No. 7, Publication 4656, 1966.

[6] *Forecasting from Harmonic Periods in Precipitation,* Smithsonian Miscellaneous Collections, vol. 148, No. 8, Publication 4659, 1966.

vary from place to place and from time to time because of atmospheric differences in transparency which alter timing. So each station must be treated separately, and atmospheric confusion eliminated. To accomplish the elimination of atmospheric confusion, I divide the year into seasons: January-April; May-August; September-December. I also treat in two separate groups intervals when Wolf sunspot numbers are $\gtrless 20$. Finally, I divide the basic interval, 1870-1949, approximately into halves, because forestry, manufacturing, and gas-propelled transportation, accompanying population increases, change the transparency of the air. See figure 1.

In official publications of monthly weather tabulations *all* available years are generally averaged into monthly normals. I found it necessary to distinguish in separate groups the months when Wolf numbers of sunspots are $\gtrless 20$. For there are important differences between these groups both in mean amplitude and in run through the year. So the monthly percentages of normal were computed by Mr. Jon. Wexler to suit two sets of monthly normals, with Wolf numbers $\gtrless 20$.

The elimination of the atmospheric confusion of phases, to which I have just referred, required electronic tabulations of no less than 222 independent groups of precipitation values for each of the 23 foreign stations listed below. My assistant, Mrs. Lena Hill, and I have received from Mr. Wexler for each station a packet of electronically printed paper 15 inches square and $\frac{3}{4}$-inch thick. It required us to work about 2 months to make the desired forecast for each station, after we received these sets of 222 tabulations made by Mr. Wexler. Some years earlier he also had prepared the records of precipitation for 32 United States cities forecasted in Smithsonian Publication 4390, and for the 10 temperature stations forecasted in Publication 4471.[7]

CLASSIFICATION

The following nomenclature is adopted (see figure 1):

Category 1, Wolf sunspot numbers <20. Category 2, Wolf numbers >20.

Division 1, years 1870-1909. Division 2, years 1910-1949.

Then for periods $\frac{273}{63}$ up to $\frac{273}{18}$ the year is subdivided as follows:

January to April; May to August; September to December.

[7] *A Long-Range Temperature Forecast,* Smithsonian Miscellaneous Collections, vol. 143, No. 5, Publication 4471, 1961.

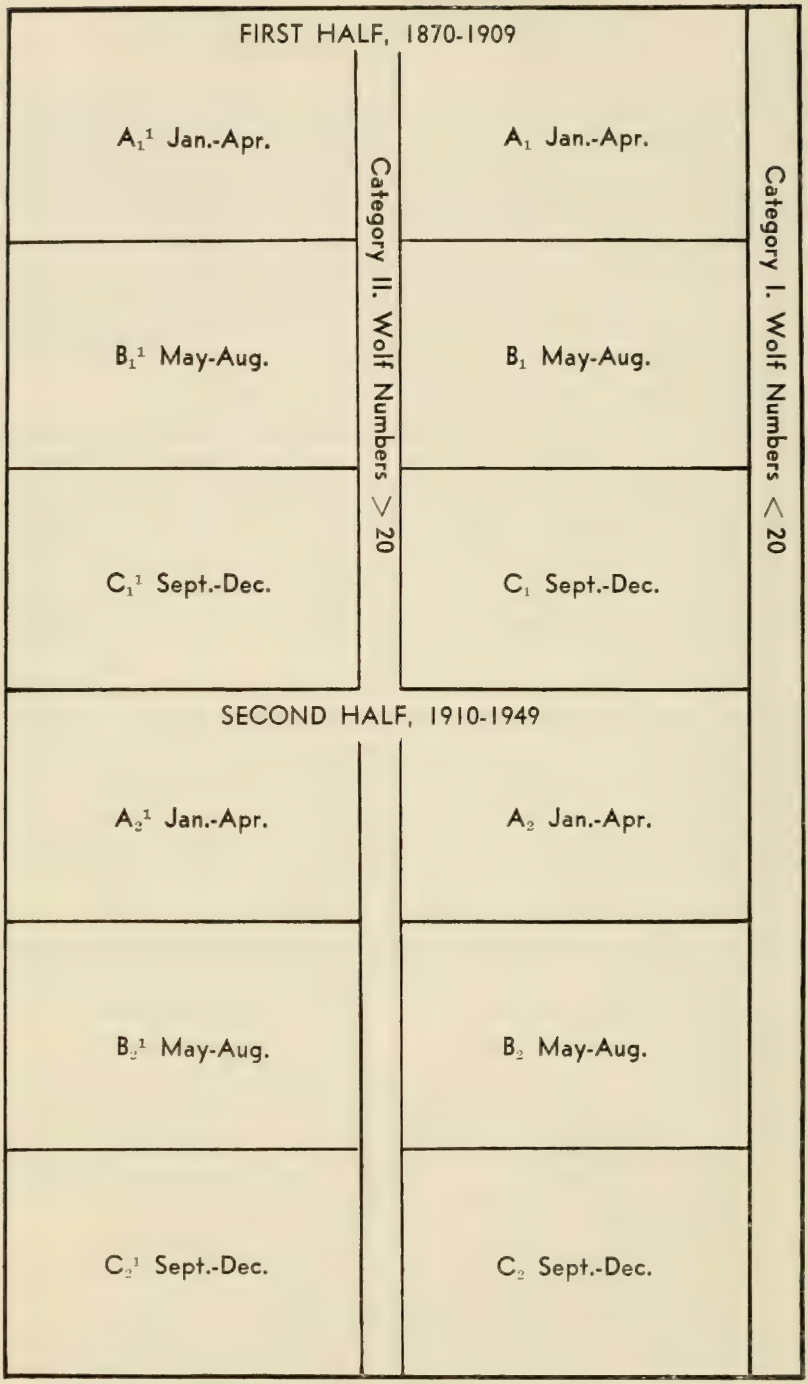

Fig. 1.—Groups of harmonic periods. Distribution of records for periods under 16 months.

This subdivision of the records requires electronic tabulation for each city to make 222 separate tables, as follows:

The 15 periods, $4\frac{1}{3}$ months to $15\frac{1}{6}$ months,	$3\times15\times2\times2=180$
The 9 periods, $18\frac{1}{5}$ months to $45\frac{1}{2}$ months,	$9\times2\times2 \quad = 36$
The 3 periods, $54\frac{3}{5}$ months to 91 months,	$3\times2 \quad = 6$
	Total 222

Table 1.—*Periods, harmonics of 273 months, used for forecasting*

Fraction	Months	Fraction	Months	Fraction	Months
1/3	91	1/12	22 3/4	1/27	10 1/9
1/4	68 1/4	1/14	19 1/2	1/28	9 3/4
1/5	54 3/5	1/15	18 1/5	1/30	9 1/10
1/6	45 1/2	1/18	15 1/6	1/33	8 3/11
1/7	39	1/20	13 13/20	1/36	7 7/12
1/8	34 1/8	1/21	13	1/39	7
1/9	30 1/3	1/22	12 9/22	1/45	6 1/15
1/10	27 3/10	1/24	11 3/8	1/54	5 1/18
1/11	24 9/11	1/26	10 1/2	1/63	4 1/3

DATES

The dates given in table 2 may be used to separate ($SS>20$ and $SS<20$) groups of months.[8]

Table 2.—*Intervals for Wolf Sunspot Numbers* $\gtrless 20$

SS > 20	
July 1857—Aug. 1865	Mar. 1868—Apr. 1875
Jan. 1880—July 1886	May 1891—Nov. 1898
July 1903—Mar. 1910	Jan. 1915—July 1921
Apr. 1925—May 1931	Mar. 1935—May 1942
Mar. 1945—Jan. 1953	May 1955—(May 1962)
SS < 20	
Jan. 1854—June 1857	Sept. 1865—Feb. 1868
May 1875—Dec. 1879	Aug. 1886—Apr. 1891
Dec. 1898—June 1903	Apr. 1910—Dec. 1914
Aug. 1921—Mar. 1925	June 1931—Feb. 1935
June 1942—Feb. 1945	Feb. 1953—Apr. 1955

Supplementary dates.—In our use of tables of periods in weather for forecasting beyond 1957, it is necessary to make extrapolations

[8] SS stands for sunspots.

for Wolf numbers beyond 1962 from the table of dates (table 2). Ths is done (of course with marginal uncertainty) by averaging the intervals (given above) in months of SS>20 and SS<20, and assuming that future sunspot intervals will be approximately the same as these averages. The uncertainty will not lead to important errors of forecasts, for generally the curves representing SS>20 and SS<20 for the periods are similar for a given period, and differ but a few months, or even not at all, in phases. I use for future intervals after 1962: for SS>20, 84 months; for SS<20, 54 months.

PLACES SELECTED FOR FORECAST STUDY

Table 3.—*Cities where precipitation is forecasted*

In Europe: Greenwich, Paris, Madrid, Uppsala, Copenhagen, Berlin, Vienna, Rome, Sibiu, Moscow, Kief, Athens, Orenburg

In Asia: Nagpur, Tokyo

In Austral-Asia: Adelaide, Wellington

In Africa: Tunis, Lagos, Johannesburg, Cape Town

In South America: Rio de Janeiro, Buenos Aires

Note.—Records for Rome were unavailable to Mr. Wexler after 1930. From 1950 onward the effects of the hydrogen bombing prevented any good forecasts for Rome up to 1962, and left no means of knowing what, if any, adjustments for scale and level should be made, 1963-1970. I will use one figure to show that before 1930 Rome reacted to the periodic impulses as well as other stations.

Records for Orenburg were so very irregular in amplitudes that no forecast was prepared.

INFLUENCE OF HARMONIC PERIODS

All of the 27 harmonics appeared implicitly in the records of precipitation in sufficient amplitudes to be of importance for controlling precipitation in all of 55 stations so far studied in the world. All of the 27 periods approximate in form to sine curves, when cleared of overriding subperiods and graphed. As stated above, their phases are different in different places, in different times, and suffer different displacements of phases, varying with length of period. This leads to the classification above shown in figure 1, and to another measure, as about to be explained.

Combinations among periods $4\frac{1}{3}$ to $13^{13}/_{20}$.—In the eighty years from 1870 to 1949 there are 240 repetitions of the period of $4\frac{1}{3}$ months and 26 repetitions of 91 months. The other periods lie between these limits as regards repetition. With the separations into groups shown in figure 1, periods where Wolf numbers are >20 include more entries than those where Wolf numbers are <20. For some periods, notably $13\frac{13}{20}$ months, but also for others, some groups have as few as 3, 2, or only 1 repetition. But even for the large groups the number of repetitions is in some cases so small that mean values obtained by electronic computation have little weight. To have stronger mean values for computing forecasts from the forms and amplitudes for all periods used, we combine the electronic mean values for periods $4\frac{1}{3}$ months up to $15\frac{1}{6}$ months in groups of 6 (or of 5) columns. Here I quote from Smithsonian Publication 4545, pp. 26, 27.

The combination of 6 member columns into a general mean, as we do for periods less than $15\frac{1}{6}$ months, will best be understood by a numerical example. The letters a, b, c denote, respectively, data of January-April; May-August; September-December. Subscripts 1 and 2 with them mean first and second halves of the records. As expected, these columns are not in the same phase. The signs, ok, ↑, and ↓, show how much the columns must be moved up or down bodily to be brought into the best posture for uniform phases. When the mean percentage departures from normal in the final column of the table 5 are used in the summation for prediction, the columns marked "ok" are to be replaced by the general mean column *without shifting*. The general mean values are to be *lowered* 2 months at b_1, *lowered* 3 months at b_2 and *raised* 1 month at a_2, so as to be in proper phases in the summation.

Table 4—*Berlin. Period, 7.0 months. Wexler's table. Means.*[1]

	Cat. 2, Div. 1.			Cat. 2, Div. 2	
a_1 ↑3	b_1 ↑2	c_1 ok	a_2 ↓1	b_2 ↑3	c_2 ok
94	96	93	114	94	100
97	100	96	105	97	100
99	99	96	103	105	101
99	95	91	100	109	97
99	99	94	105	109	97
99	95	101	103	115	99
98	91	95	109	112	98

[1] From Smithsonian Publication 4545, p. 26.

Table 5—*Berlin. Period, 7.0 months.*
Rearranged table with symbols unchanged.[1]

	Cat. 2, Div. 1			Cat. 2, Div. 2			
a_1 ok	b_1 ↑2	c_1 ok	a_2 ↑3	b_2 ↓3	c_2 ok	Sums Σ	General mean ÷6
99	99	93	109	109	100	+ 9	+1
99	95	96	114	115	100	+19	+3
99	99	96	105	112	101	+12	+2
98	95	91	103	94	97	—22	—4
94	91	94	100	97	97	—27	—4
97	96	101	105	105	99	+ 3	+0
99	100	95	103	109	98	+ 4	+1

[1] From Smithsonian Publication 4545, p. 27.

Beyond $15\frac{1}{6}$ months in period, practically every period, when plotted, betrays confusion, for shorter harmonic periods override the period sought. This requires what is by far the most arduous computation of all. After the electronically prepared tables are received from Mr. Wexler they must be treated to clear the overriding shorter harmonics away. It is sometimes difficult to decide which submultiples are present until after one or two futile trials. Such repeated trials with periods 54 to 91 months in length are very tedious.

I will refer to examples of this procedure from Smithsonian Publication 4545, pp. 22, 23, and 32, and cite the studies of Rome, Kief, and Cape Town of the present paper, figures 2, 3, and 4. It will be clear from these examples that stations in far separated regions of the world present harmonics of 273 months as approximately perfect sine curves, of large percentage amplitude, when confusing harmonic submultiples are removed. The foregoing must be convincing, I think, that our discovery is sound of important harmonic periods in weather related to the master period of exactly 273 months.

FORECASTS OF PRECIPITATION FOR 23 FOREIGN CITIES

Preceding pages have shown that 27 periods which are exact harmonics of 273 months may be so fully cleared of confusion as to display in all cases approximately sine curves in form. The basic interval for determination of forms and amplitudes of these harmonic periods in this paper covers records of precipitation of the 23 cities from about 1870 through 1949 or 80 years. See table 6. In this basic interval are 26 repetitions of 91 months, 240 of $4\frac{1}{3}$ months. We have determined the percentage of normal monthly precipitation from 1870 to 1949 for 27 periods at 23 cities. Therefore, knowing the average form and amplitude of these 27 periods for 80 years preceding 1950, it was assumed that by adding the amplitudes of the 27 periods, as thus determined, throughout later years a fair monthly forecast can be extrapolated covering the interval 1950 through 1970. Favorable results had been obtained by such methods for 32 cities in the United States, as published by Smithsonian Publication 4390. Figure 5, as an example, graphs the forecast and observed values from 1938 through 1949 for Lagos, Nigeria. The years 1938 through 1949, though lying *within* the base period, 1870 through 1949, are, it must be conceded, as fair a test of the method as those following 1949. For no observation of a single year of the march of weather, 1938-1949, can affect the "forecast" for that year by more than $\frac{12}{80\times 12}$, or $1\frac{1}{4}$ percent.

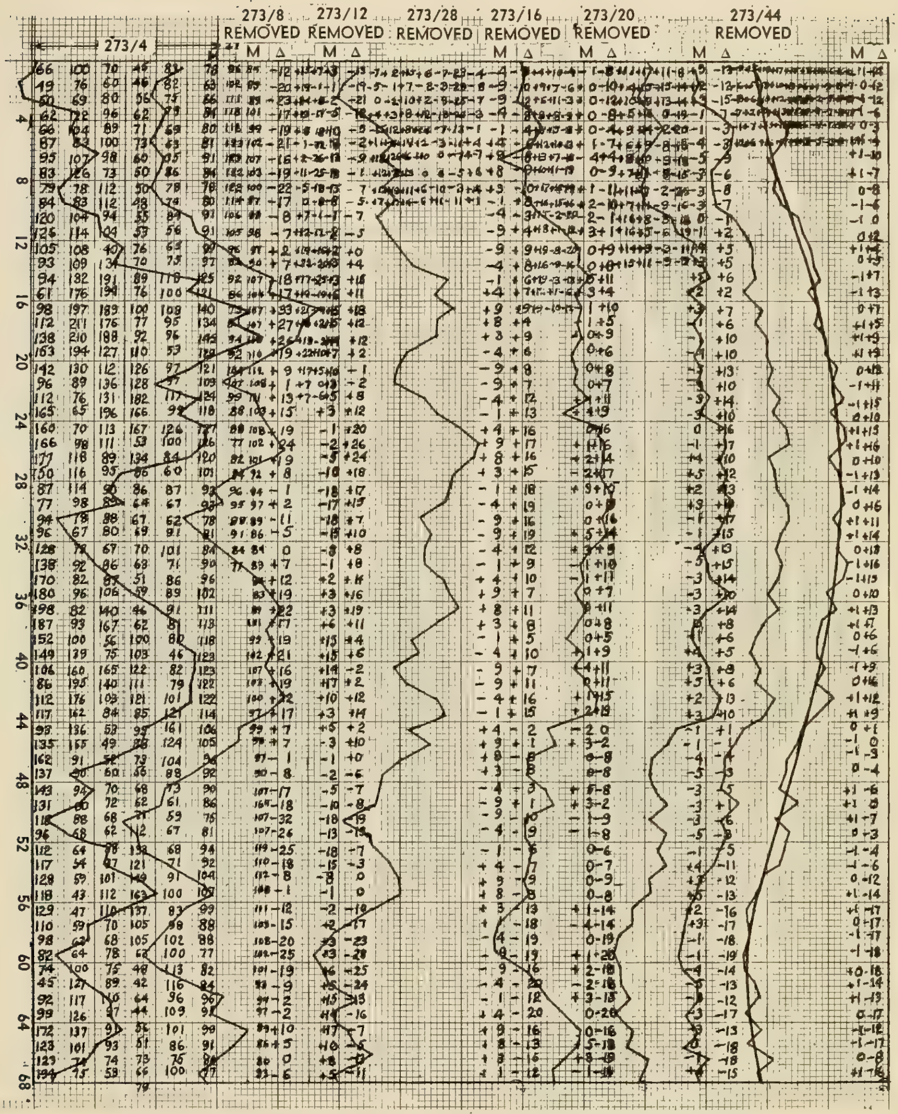

FIG. 2.—Rome, Italy. Precipitation. 68¼-month period cleared.

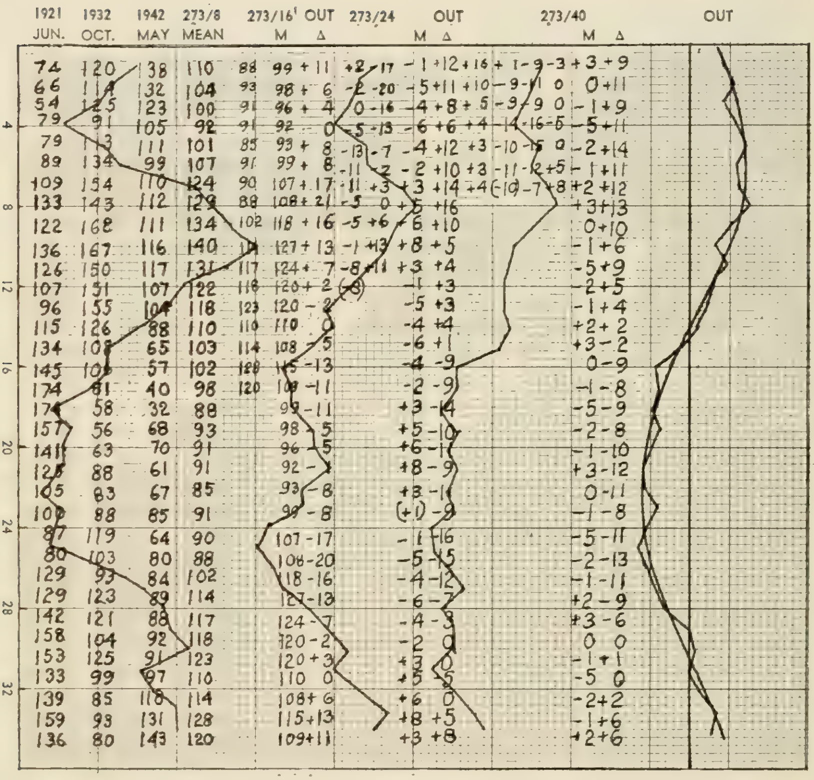

FIG. 3—Kiev, U.S.S.R. Precipitation. 34⅛-month period cleared.

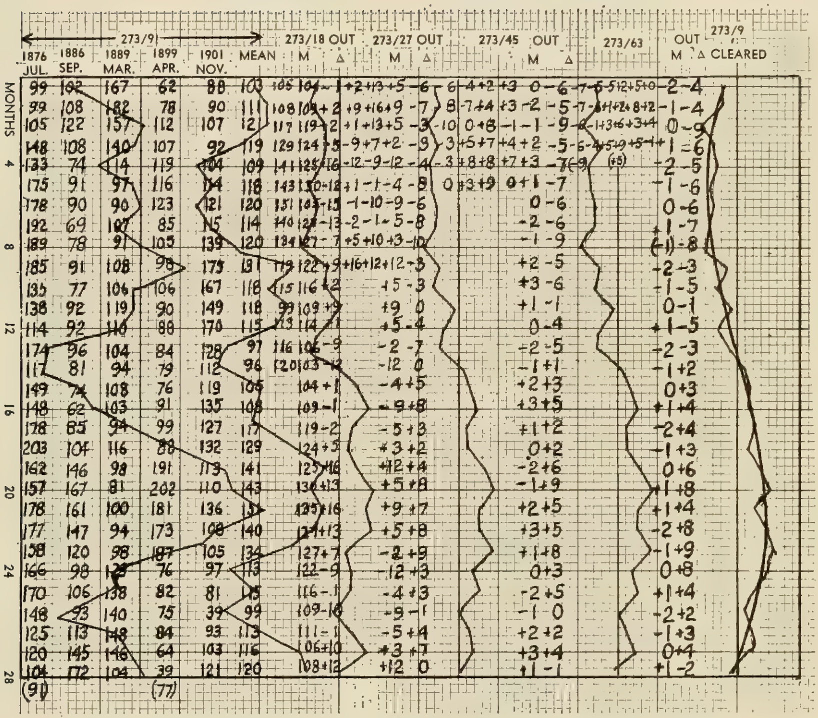

FIG. 4.—Cape Town, South Africa. Precipitation. 30⅓-month period cleared.

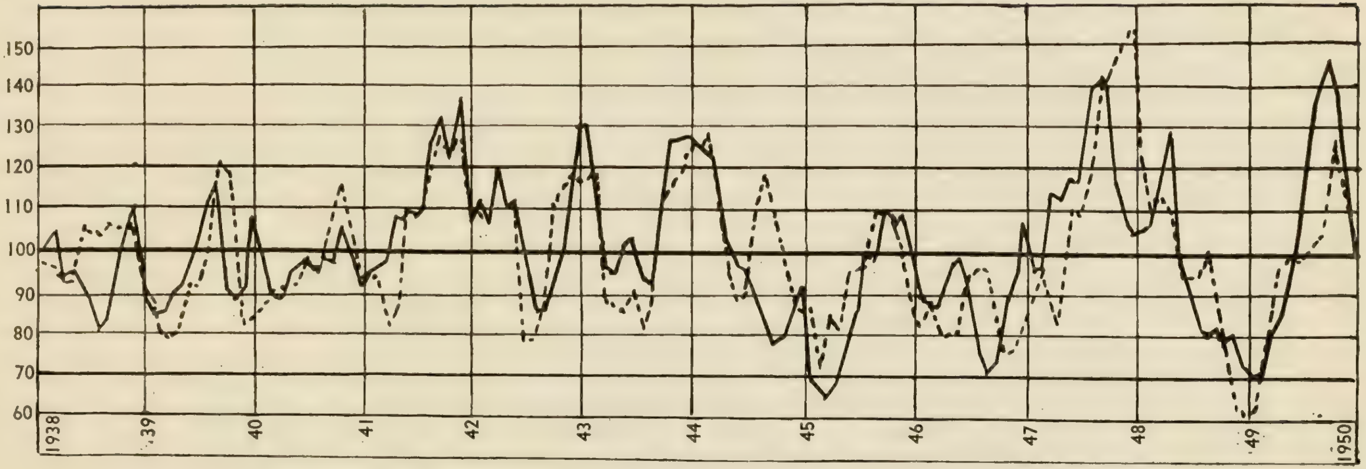

FIG. 5.—Lagos, Nigeria. Monthly precipitation. Forecast and observed values, 1938-1949.

Forecast: solid line ——— Observed: dotted line ......

TABLE 6.—*Normal monthly precipitation, 1870 through 1949, expressed in tenths of an inch or in millimeters.*

A = Wolf number > 20. B = Wolf number < 20.

Month	ADELAIDE AUSTRALIA [In tenths of an inch]		ATHENS GREECE [In millimeters]		BERLIN GERMANY [In millimeters]		BUENOS AIRES ARGENTINA [In millimeters]		CAPE TOWN SOUTH AFRICA [In tenths of an inch]		COPENHAGEN DENMARK [In millimeters]	
	A	B	A	B	A	B	A	B	A	B	A	B
January	7.3	9.2	48.3	60.7	40.9	45.7	87.2	84.1	8.7	5.4	36.9	40.3
February	8.2	7.4	44.3	42.6	40.0	32.9	70.1	74.3	5.6	5.3	31.3	29.5
March	12.0	9.4	33.2	32.5	42.2	37.7	144.2	102.8	6.8	10.0	37.4	30.8
April	17.9	16.9	18.5	20.6	40.5	38.2	90.6	91.0	19.1	20.0	33.6	35.3
May	26.8	25.6	19.0	21.9	47.8	47.0	95.9	62.5	44.6	34.2	39.8	42.6
June	31.7	28.3	19.7	15.5	52.6	60.4	61.3	61.4	40.4	43.0	46.0	51.4
July	23.6	26.0	5.1	6.8	73.3	74.5	68.4	50.3	35.7	38.2	64.5	63.9
August	22.4	25.8	13.0	6.7	50.0	66.4	81.5	52.9	37.6	31.6	68.2	69.5
September	22.5	19.2	14.4	18.4	41.7	44.2	73.3	87.6	23.9	22.6	54.3	56.4
October	16.3	18.5	31.7	48.1	44.3	51.6	93.8	82.4	17.1	15.2	59.3	61.3
November	12.2	11.5	69.0	55.4	43.2	45.2	85.0	84.9	10.8	9.1	46.1	51.2
December	11.1	10.0	66.1	73.8	39.1	48.9	92.0	102.6	8.3	8.9	45.1	45.6

Month	GREENWICH ENGLAND [In millimeters]		JOHANNESBURG SOUTH AFRICA [In tenths of an inch]		KIEF U.S.S.R. [In millimeters]		LAGOS NIGERIA [In tenths of an inch]		MADRID SPAIN [In millimeters]		MOSCOW U.S.S.R. [In millimeters]	
	A	B	A	B	A	B	A	B	A	B	A	B
January	45.7	58.4	55.4	64.8	37.8	35.0	13.1	9.0	24.9	35.8	25.7	29.3
February	38.6	40.0	47.6	52.8	35.7	34.8	13.8	20.1	31.2	36.7	24.6	26.9
March	42.2	40.1	38.2	48.0	49.0	41.9	38.7	40.2	37.4	43.2	46.9	32.3
April	46.9	41.6	23.7	14.8	54.8	43.6	54.1	59.1	45.1	43.1	29.8	30.8
May	49.2	42.9	7.9	9.3	49.5	55.0	93.8	114.9	30.7	46.5	48.2	44.1
June	50.4	47.3	3.0	2.1	81.3	70.2	178.6	178.3	31.5	32.1	68.6	68.0
July	58.7	39.0	5.2	3.4	84.5	72.8	112.4	103.0	9.1	10.9	80.4	81.0
August	60.3	57.4	4.7	4.1	61.2	65.9	33.0	22.7	13.7	9.2	79.5	68.8
September	43.0	52.2	9.4	10.0	51.8	41.8	57.1	55.7	37.6	34.1	50.8	61.2
October	56.3	67.8	29.2	23.7	37.2	51.8	82.4	82.3	54.2	43.0	49.1	51.5
November	59.4	60.1	48.1	49.6	50.7	45.0	24.3	29.5	51.0	55.0	38.6	40.7
December	54.6	55.5	54.7	56.0	35.7	47.1	12.0	9.9	38.5	42.9	36.8	36.8

TABLE 6.—*Normal monthly precipitation, 1870 through 1949, expressed in tenths of an inch or in millimeters.—Continued.*

A = Wolf number > 20. B = Wolf number < 20.

Month	NAGPUR INDIA [In tenths of an inch]		ORENBURG U.S.S.R. [In millimeters]		PARIS FRANCE [In millimeters]		RIO DE JANEIRO SOUTH AMERICA [In millimeters]		ROME ITALY [In millimeters]		SIBIU ROUMANIA [In millimeters]	
	A	B	A	B	A	B	A	B	A	B	A	B
January	4.7	4.9	18.6	24.7	40.7	46.0	12.4	14.5	7.2	9.0	30.6	26.9
February	5.6	8.0	18.4	13.0	33.9	40.6	9.8	13.5	8.2	7.0	24 9	25.3
March	4.3	6.3	21.5	20.9	42.7	39.2	12.3	13.4	7.8	7.5	37.3	32.6
April	6.0	5.7	21.4	22.4	45.3	45.2	10.5	10.2	7.6	8.0	54.2	51.3
May	8.6	6.9	35.5	38.6	51.0	53.5	6.6	6.7	5.9	5.9	83.7	85.3
June	74.9	92.5	36.9	45.4	52.6	54.4	5.2	5.6	4.5	4.2	113.1	117.7
July	141.5	152.2	39.0	40.3	62.1	57.2	3.3	4.5	1.8	1.6	82.1	98.5
August	115.5	106.6	33.7	30.6	66.0	52.9	3.8	4.1	2.5	2.2	83.1	72.4
September	78.3	80.5	21.5	29.5	46.1	50.2	6.6	6.1	8.0	6.8	59.6	47.8
October	22.2	21.8	37.2	32.6	55.5	61.9	8.3	8.2	15.0	12.3	46.4	45.1
November	6.9	7.4	32.5	29.6	52.7	51.4	10.1	9.2	11.4	12.0	38.4	31.4
December	3.5	4.0	26.0	26.4	48.6	52.8	13.4	12.7	10.3	10.4	30.7	27.5

Month	TOKYO JAPAN [In millimeters]		TUNIS TUNISIA [In millimeters]		UPPSALA SWEDEN [In millimeters]		VIENNA AUSTRIA [In millimeters]		WELLINGTON NEW ZEALAND [In tenths of an inch]	
	A	B	A	B	A	B	A	B	A	B
January	53.7	47.6	51.5	63.3	33.6	34.8	40.3	39.4	27.3	32.9
February	71.2	78.5	50.3	52.8	29.2	25.9	41.2	36.9	34.6	30.6
March	110.2	105.5	39.6	40.5	31.4	27.9	48.3	44.7	26.1	34.8
April	128.1	131.8	35.2	34.2	30.1	30.4	55.8	53.0	33.9	41.1
May	148.0	144.0	17.1	23.1	41.1	39.0	71.2	73.0	52.6	43.6
June	157.4	177.6	12.5	8.8	46.0	49.8	67.9	73.1	42.5	49.0
July	129.7	144.6	2.5	2.7	65.3	69.3	69.8	85.9	55.4	52.8
August	144.6	148.9	6.5	5.8	65.0	77.7	58.4	75.2	42.0	50.6
September	231.2	227.6	21.9	33.0	53.1	52.4	56.1	46.2	38.1	39.0
October	216.7	197.0	38.8	47.3	52.5	50.9	55.2	55.7	41.3	41.1
November	94.6	102.8	48.5	68.4	45.8	42.3	47.5	48.3	35.1	33.2
December	57.9	53.0	71.8	65.3	45.3	39.7	47.5	49.3	37.5	32.1

SMOOTHING

In figure 5 the monthly "forecasted" values represent the *average* influence of from 26 to 240 repetitions of the harmonic periods. So they may be fairly regarded as "smoothed" values. To be fairly compared with them, the "observed" precipitation, 1938 through 1949, must also be "smoothed." Heretofore in my publications I have employed the "5-month consecutive" smoothing. But this frequently tends to displace maxima or minima by 1 or even 2 months. I now introduce in figure 5 a better formula. It still involves 5 months, but as follows: $\frac{1}{10}(a+2b+4c+2d+e)$. This gives the central month, c, two-thirds as much weight as the other 4 months combined, instead of one-fourth the weight of the other 4 months combined, as was the case in "5-month consecutive" smoothing.

EFFECT OF HYDROGEN BOMBS

I had intended to present the foreign city forecasts of precipitation after 1950 nearly as I had published forecasts for 32 American cities in Smithsonian Publication 4390. But when the United States and the U.S.S.R., about 1950, began exploding powerful hydrogen bombs, whose products rose to immense heights and remained long in the atmosphere, the new conditions might well invalidate my assumption that the average forms and amplitudes of 27 periods which prevailed 1870-1949 would indicate what precipitation would follow in succeeding years.

I found evidence to support the following conclusions:

(1) That my method of forecasting gave good worldwide results for the decade, 1940-1949.

(2) That it is less successful generally, 1950-1963, except for a few stations during 1953-1957.

(3) That there was enough probability that it would hold, 1965-1970, so that tabulation of forecasts for those years may be useful.

A brief method of demonstrating conclusions (1) and (2) lay in the presentation of spot graphs connecting predictions with observations. For if the summation of average forms and amplitudes of 27 periods, as they were from 1870 through 1949, *perfectly* represented the observed march of percentages of normal precipitation for those years, then the spot graph for 1940-1949 would be a 45° line with all spots lying upon it. A glance at *World Weather Records* shows, of course, that no such perfection can be expected. Take for example only the month of June at Athens:

Year observed:	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
Precipitation (in mm.):	8.6	13.3	18.4	0.6	0.1	0.4	48.8	23.7	38.9	0.4

Normal: 15.3 millimeters.

Yet even for Athens the spots on graphs should clearly *tend to approach* the 45° line. They do in the decades preceding 1950, but scatter widely after 1950.

I now draw attention to figures 6, 7, 8, 9, 10, 11, which present spot graphs of forecasts and observed values smoothed by $\frac{1}{10}(a+2b+4c+2d+e)$. The figures show for Adelaide, Athens, Greenwich, Buenos Aires, Johannesburg, and Uppsala, precipitation in percentages of normal. The bombing, beginning about 1950 was discontinued for several years, but revived with monstrous power about 1958. My predictions, 1950-1964, seem much devalued, except for some stations during the quieter years 1955-1958. I have spot graphs for many other stations. Nearly all in some measure tell the same story as those here presented. It was noticed that at Tokyo the years 1943-1945 fell in the bombing group, for at that time occurred the bombing of Hiroshima and Nagasaki, though done with comparatively weak plutonium bombs. These caused only a moderate effect compared with that caused later by hydrogen bombs.

THE FORECAST FOR NAGPUR

Nagpur is the only one of the 23 foreign stations which has a purely monsoon precipitation. Nearly all of its yearly precipitation falls in the months June, July, August, and September. In the 9 years, 1941-1949, *World Weather Records* tabulate 447 inches, of which 385 inches, or 86 percent, falls in those 4 months. The forecast for Nagpur was prepared identically as for other stations. That is, Wexler computed the percentages of normal monthly precipitation for 80 years, tabulating 222 separate tables of departures from normal. We added the separate contributions of the 27 periods for each month 1938-1949. We also smoothed the *observed* monthly precipitation for these 12 years by the formula $\frac{1}{10}(a+2b+4c+2d+e)$. These monthly percentages of normal, forecasted, and smoothed-observed, were plotted for Nagpur for years 1944-1949, but they seemed meaningless because of the monsoon distribution. I omit them here.

I, therefore, reduced the monthly *departures* from *normal* to millimeters, forecasted and smoothed-observed, 1944-1949. This *actual* precipitation is plotted in figure 12. These forecasts are fully as

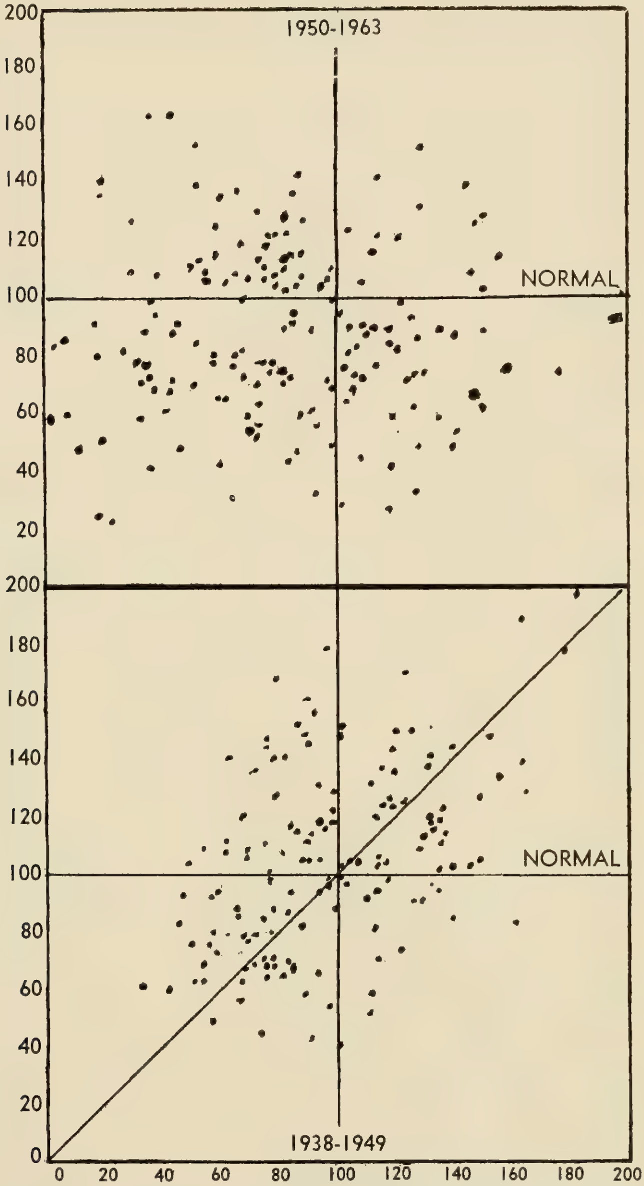

Fig. 6.—Adelaide, Australia. Precipitation, forecast and observed, 1938-1949 compared with 1950-1963, in percentages of normal, showing the effect of hydrogen bombs.

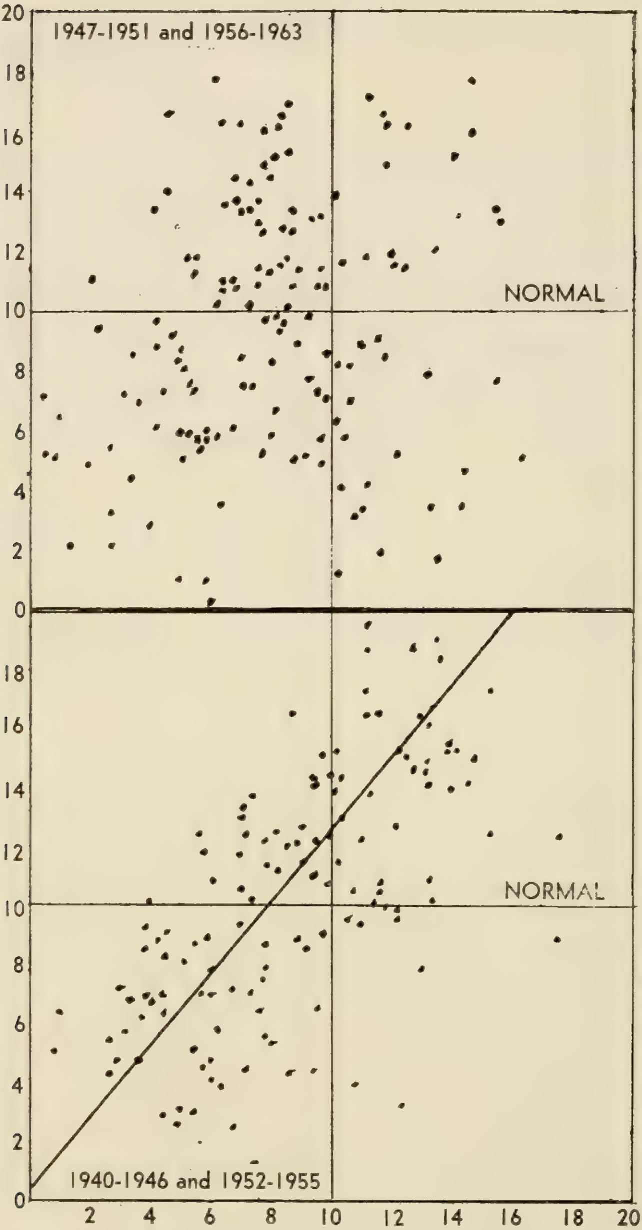

Fig. 7.—Athens, Greece. Precipitation, forecast and observed, 1940-1946, 1952-1955 compared with 1947-1951 and 1956-1963, in percentages of normal, showing the effect of hydrogen bombs.

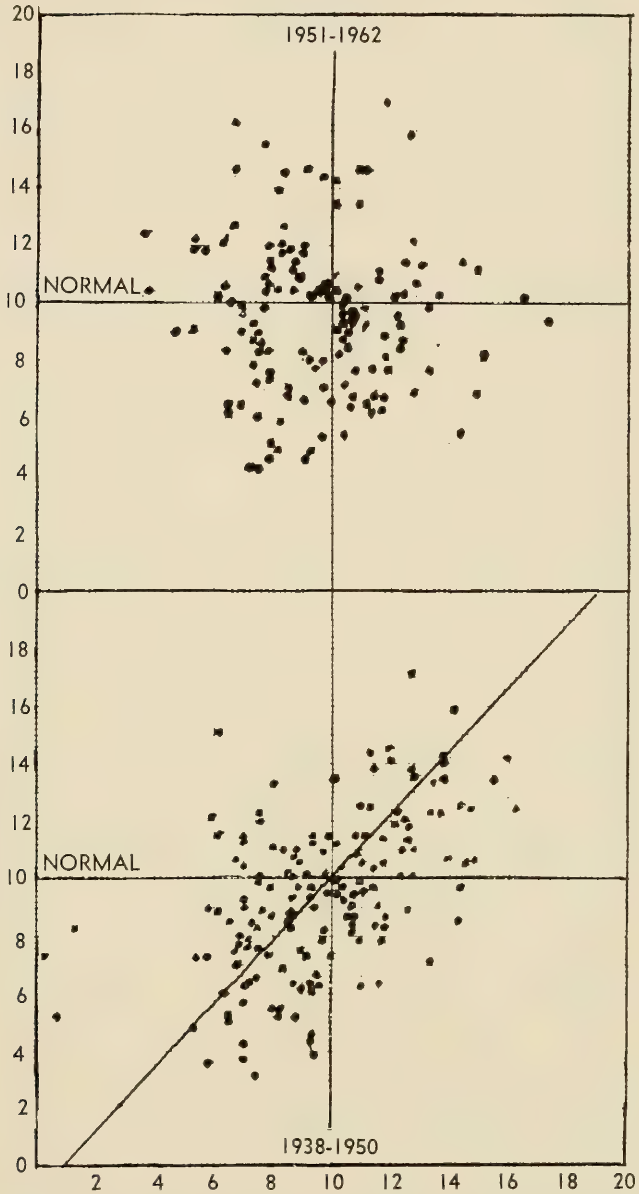

FIG. 8.—Greenwich, England. Precipitation, forecast and observed, 1938-1950 compared with 1951-1962, in percentages of normal, showing the effect of hydrogen bombs.

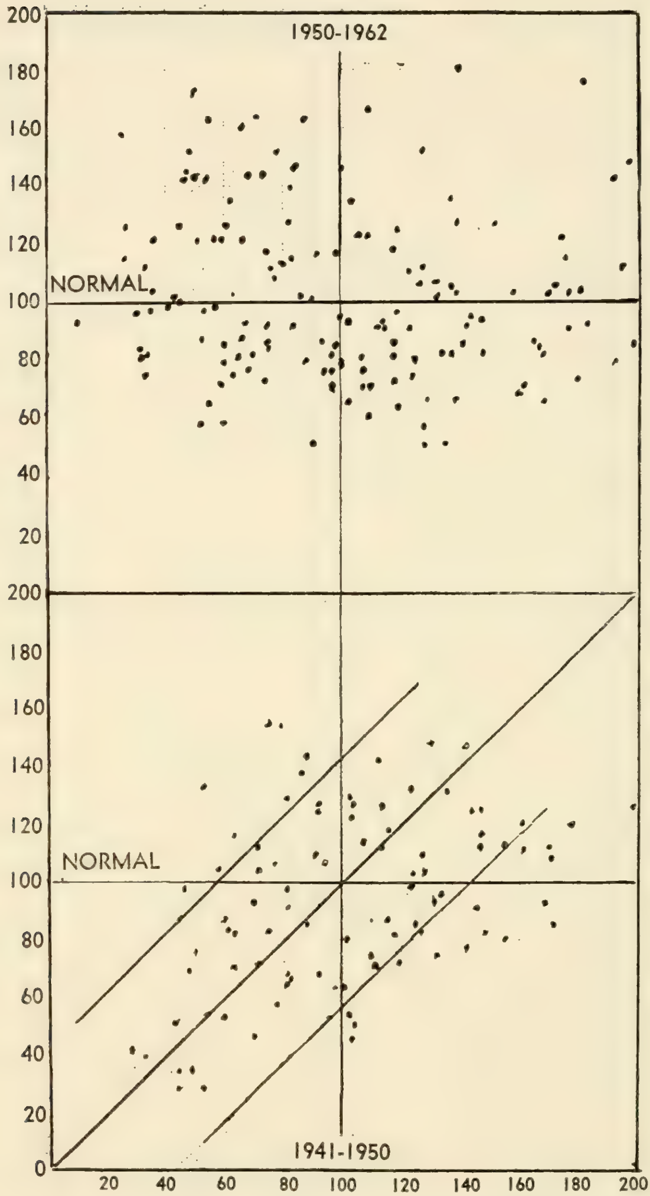

FIG. 9.—Buenos Aires, Argentina. Precipitation, forecast and observed, 1941-1950 compared with 1950-1962, in percentages of normal, showing the effect of hydrogen bombs.

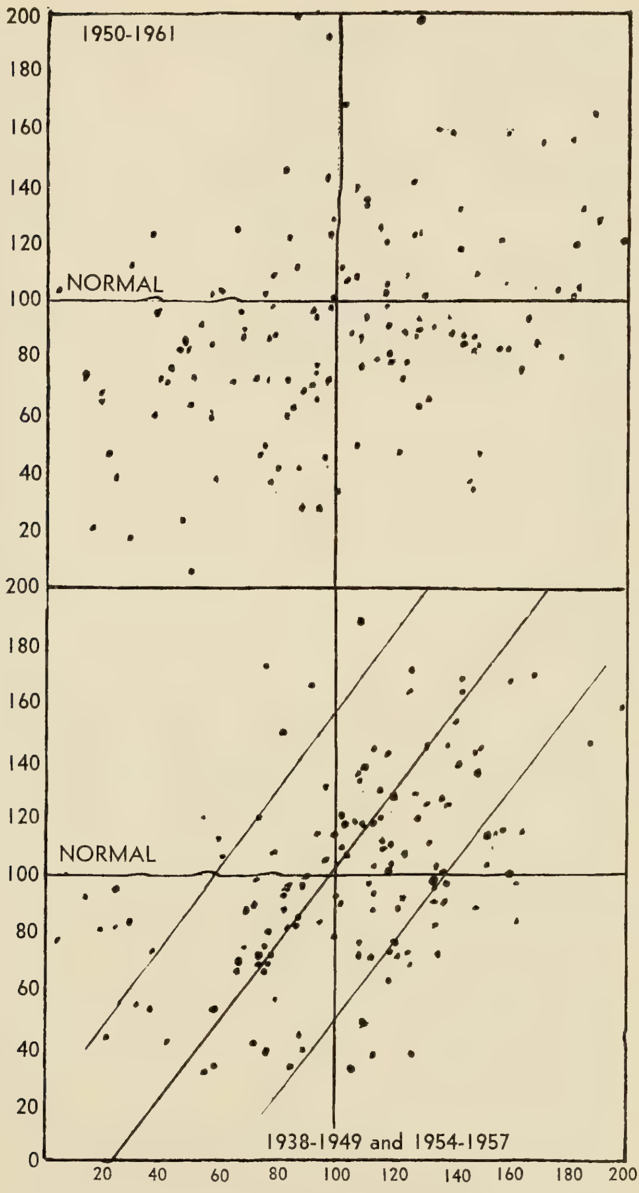

FIG. 10.—Johannesburg, South Africa. Precipitation, forecast and observed, 1938-1948 and 1954-1957 compared with 1950-1961, in percentages of normal, showing the effect of hydrogen bombs.

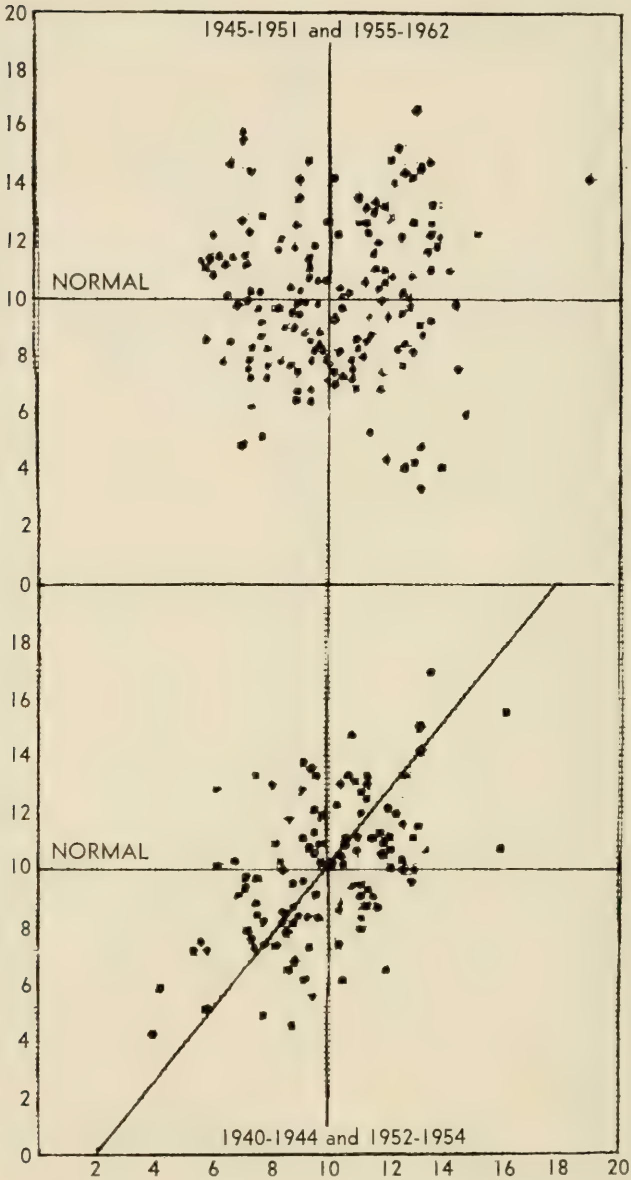

FIG. 11.—Uppsala, Sweden. Precipitation, forecast and observed, 1940-1944 and 1952-1954 compared with 1945-1951 and 1955-1962, in percentages of normal, showing the effect of hydrogen bombs.

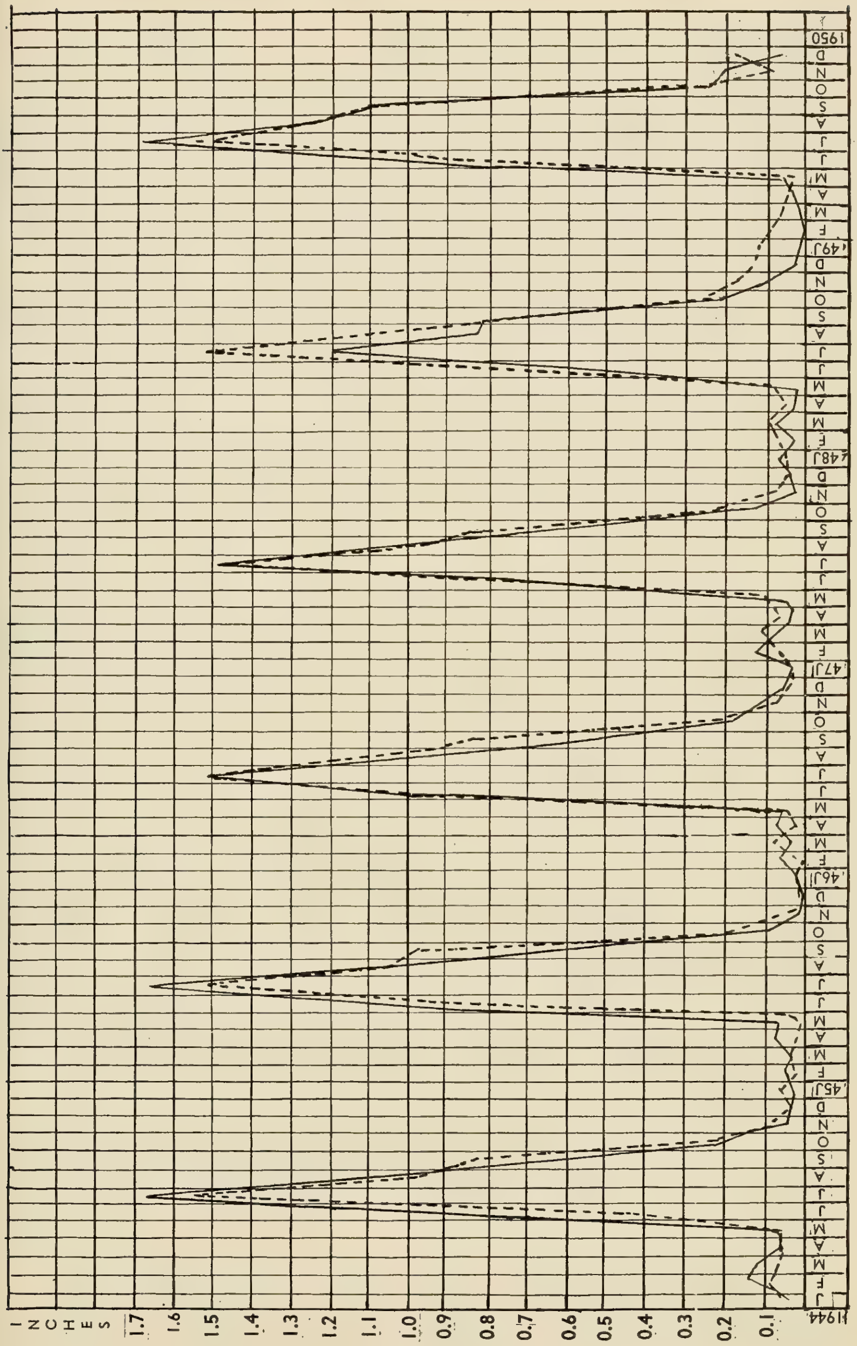

FIG. 12.—Nagpur, India, monthly precipitation (in millimeters), forecast and observed, 1944-1949.

Forecast: dotted line . . . . . . Observed: solid line ———

representative of the events through those 6 years as could reasonably be hoped for, both as to timing and quantity of precipitation. It may be noted that after February 1945 the short dotted line marks the change from Wolf sunspot numbers, *less*, to Wolf numbers *greater* than 20.

The *coefficient of correlation* at Nagpur between "forecasted-from-1870" and "smoothed-observed precipitation," 1944-1949, as observed in millimeters, has the astonishingly high percentage value +90.1 percent. Equally long-interval correlation coefficients between forecasts and smoothed-observed events for others of the 55 world stations, which we have forecasted, usually run between +50 and +70 percent. At Tokyo, 1938-1949, omitting bombing years 1944 and 1945, the coefficient of correlation indeed is higher. It reaches $+72.5 \pm 4$ percent.

The results of Tokyo precipitation are so instructive that I present in figure 13 the monthly forecast and smoothed observed precipitation, 1938-1943, with comments thereon.

COMMENTS ON FIGURE 13

This figure was prepared in long-hand by copying a section of the original computation, which was in pencil. I sent a photographic copy covering the 30 years 1933 to 1963 to Dr. Arakawa in Tokyo, about 4 years ago.

1. Figure 13 will testify that the preparation for computing long-range forecasts of weather from early records of forms and amplitudes of 27 harmonics is *very tedious*. Many of the signs and numbers copied for figure 13 were so dim in the original penciled computation that probably some errors occurred in copying them in ink. If so, such errors do not prejudice the curves of prediction and event. These are as originally drawn in ink.

2. I chose 6 years when prediction and event show large amplitudes of variation from the normal monthly values of figure 9. The extreme range of variation exceeds 130 percent of normal precipitation.

3. In the 4½ years, 1938 to June 1942, the dotted curve of observation averages about 25 percent of normal *above* the full curve of prediction. But from July 1942 through 1945 the observed curve (as sent to Dr. Arakawa) averages about 40 percent *lower* than the predicted. I attribute this to the plutonium bombing of Hiroshima and Nagasaki in 1943.

4. Even larger and more capricious discrepancies between prediction and event occurred for the years 1950 to 1953, and also for the years 1959 to 1963. This may well be due to the enormously powerful

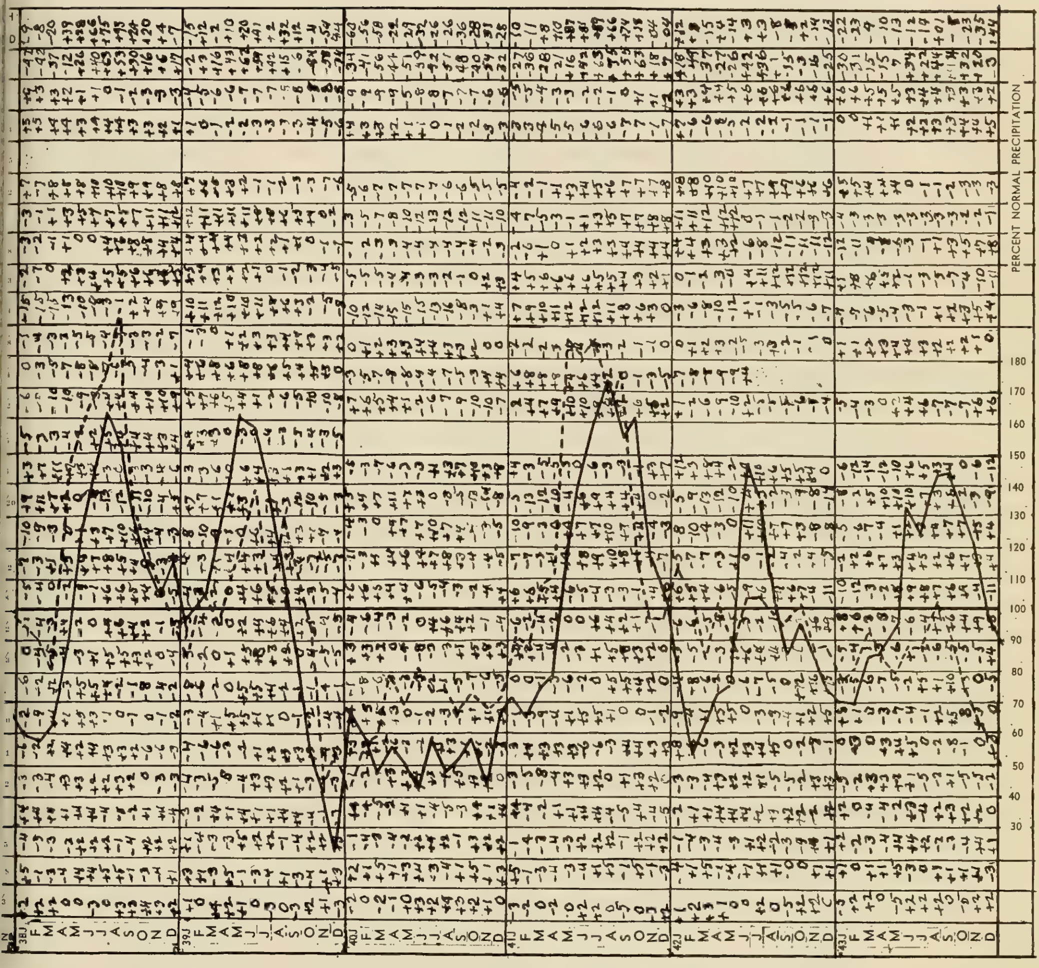

FIG. 13.—Tokyo, Japan. Monthly precipitation, forecast and observed, 1938-1943.

Forecast: solid line ——— Observed: dotted line ......

hydrogen bombs, released at high levels in the atmosphere by the U.S.S.R. and United States, about 1950 and 1958. My predictions indicate that these tremendous explosions, and their fallout, produced noticeable effects on precipitation in all continents. I have given illustrations to show this in figures 6-11.

YEARLY FORECASTS AND OBSERVATIONS

To support the value of long-range predictions made from harmonic periods found implicit in *World Weather Records,* 1870-1949, I give in figures 14-17 yearly values covering about 25 years each for four widely separated cities. The cities chosen are Buenos Aires, Copenhagen, Johannesburg, and Lagos. The yearly mean values are plotted in light lines, full and dotted, as departures from yearly normals. To make the comparison clear, both forecasted and observed yearly means are then smoothed by the formula $\frac{1}{10}(a+2b+4c+2d+e)$. It becomes fully apparent that the differences between prediction and event are much less than the average amplitudes of their common variations. Yet their agreement is disturbed after 1950 by the bombing effects considered above, and illustrated in figures 6-11, except at Johannesburg where the bombing effect is hardly noticeable. Some differences in phases occur in each illustration.

MONTHLY AND 4-MONTHLY FORECASTS

As stated above I had expected to compare monthly forecasts with observations 1950-1970, but found the bombing effect so noticeable from 1950 to 1964 at most cities that it seemed doubtful that such a comparison from 1950 would be useful. But for what it may prove, I give in table 7 forecasts monthly and 4-monthly, 1965-1970.

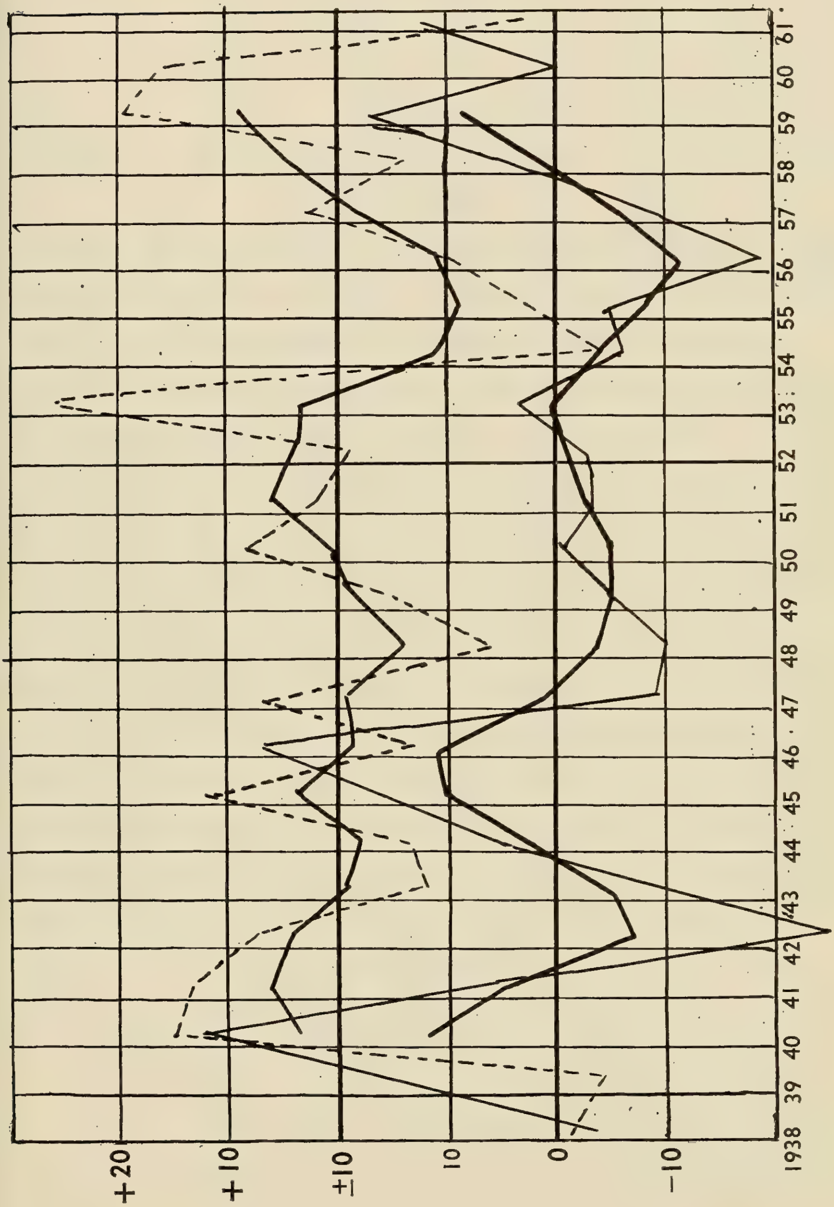

FIG. 14.—Buenos Aires, Argentina. Yearly precipitation, forecast and observed, 1938-1961.

Forecast: dotted line .... Observed: solid line ———

Smoothed: heavy solid line ———

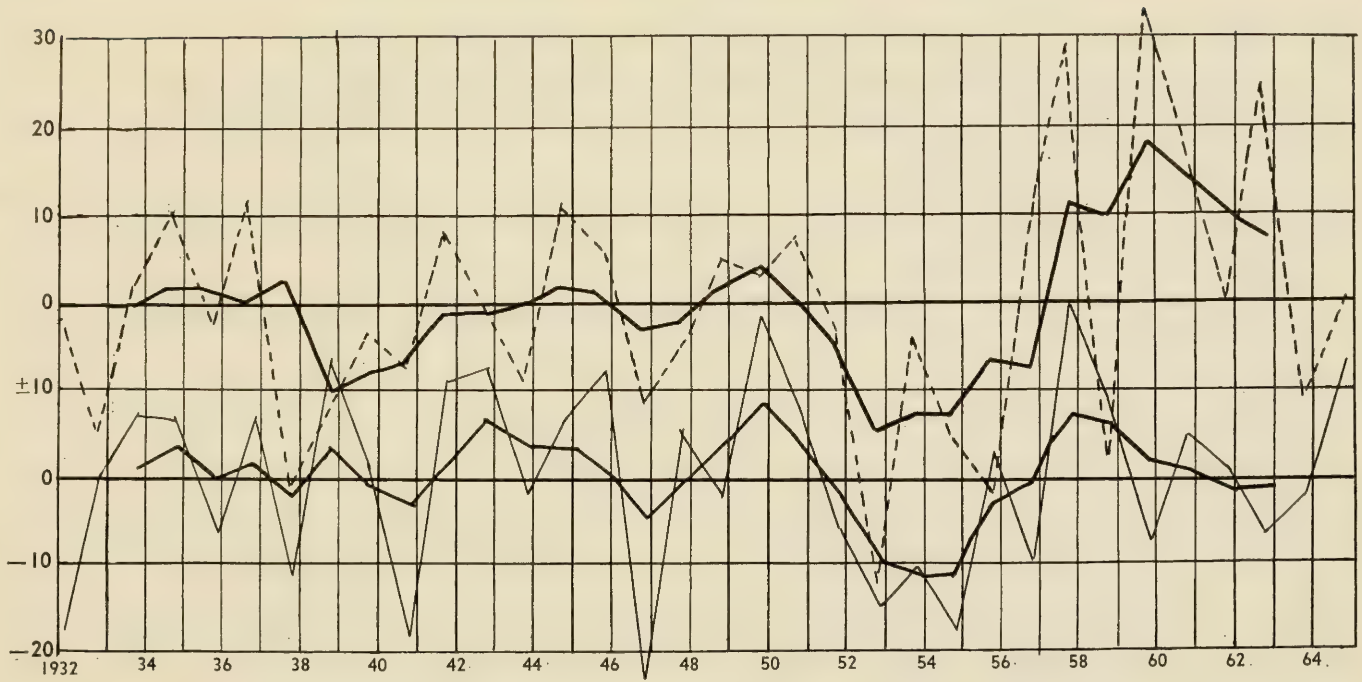

FIG. 15.—Copenhagen, Denmark. Yearly precipitation, forecast and observed, 1932-1964.

Forecast: solid line ——— Observed: dotted line ......

Smoothed: heavy solid line ———

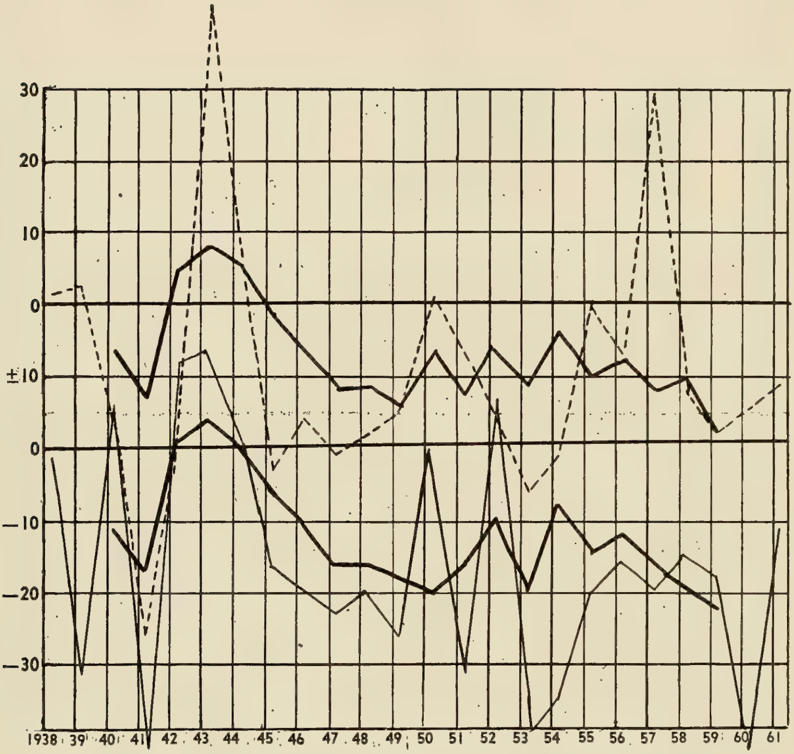

FIG. 16.—Johannesburg, South Africa. Yearly precipitation, forecast and observed, 1938-1961.

Forecast: solid line ——— Observed: dotted line ......

Smoothed: heavy solid line ———

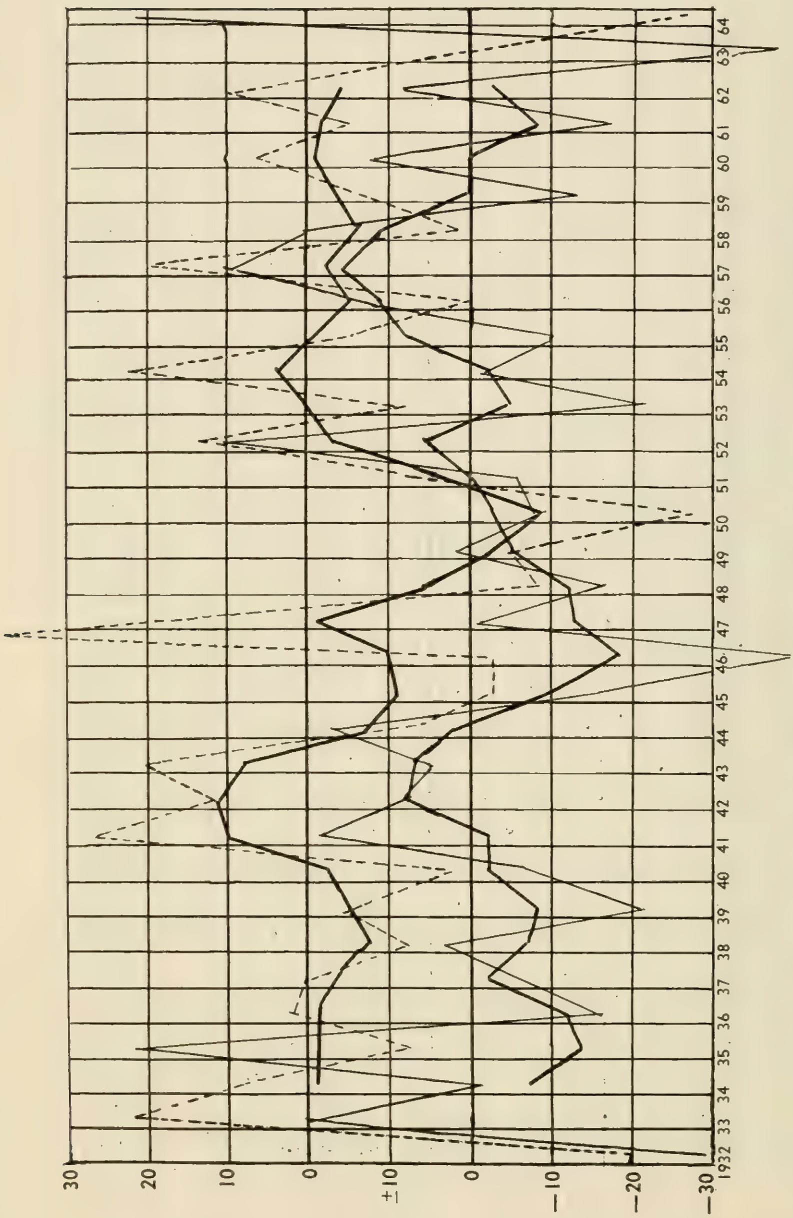

FIG. 17.—Lagos, Nigeria. Yearly precipitation, forecast and observed, 1932-1964.

Forecast: solid line —— Observed: dotted line ......

Smoothed: heavy solid line ——

TABLE 7.—*Predicted departures from normal precipitation, 1965-1970.*

A = January-April. B = May-August. C = September-December.

Period	Adelaide	Athens	Berlin	Buenos Aires	Cape Town	Copenhagen	Greenwich	Johannes-burg	Kiev	Lagos	Madrid	Moscow
1965												
A	+6	+27	—34	+1	+17	+2	—22	—106	+55	—29	—25	—16
B	—11	+30	0	—6	+55	—19	—15	—41	0	—35	+14	+70
C	+40	—89	+12	—21	—8	+58	+92	—61	—43	+73	+76	—57
1966												
A	—10	+1	—12	—51	+6	+4	—5	+20	+20	—34	+36	—62
B	—15	+27	—42	+8	—3	+1	—60	+62	—25	+32	+61	+12
C	+4	+6	+4	+37	—18	+2	—12	—17	—9	+36	—2	—53
1967												
A	+31	+42	+6	+15	—15	+1	—13	+4	+21	—55	+46	—21
B	—34	—34	+2	—23	—3	—20	—5	+89	0	+31	—36	+8
C	+3	+30	+29	+22	—8	+3	—5	+20	+17	+1	—14	—21
1968												
A	—12	+47	+22	+6	0	+10	+36	+46	+10	—27	+13	+20
B	—57	—66	—16	—16	+4	—7	—6	+13	+5	—40	—38	+84
C	+88	+14	+29	+59	—4	—13	—31	—21	+4	—25	—27	+13
1969												
A	+52	+42	+32	+69	+13	+49	+31	+17	+17	—51	+20	—18
B	—64	—73	—36	+13	+27	+22	+36	0	+10	—60	—61	+5
C	+32	—48	—37	—22	—11	—18	+13	—52	—13	+34	—45	+29
1970												
A	—40	+57	+16	+40	—22	+15	+25	+50	+28	+17	+82	—24
B	—16	—41	+13	—35	—3	+33	+10	+20	—2	+102	+32	+102
C	+92	+24	—6	+45	+22	+7	+1	—22	—16	+56	0	+15

Table 7.—*Predicted departures from normal precipitation, 1965-1970.—Continued*

A = January-April. B = May-August. C = September-December.

Period	Nagpur	Orenburg	Paris	Rio de Janeiro	Rome	Sibiu	Tokyo	Tunis	Uppsala	Vienna	Wellington
1965											
A	+5	−11	−90	+18	+20	+27	+30	+60	+9	−54	+16
B	−102	+106	+40	0	+3	+12	+18	−103	+10	+12	−11
C	−23	−33	+46	+4	+88	−16	+11	+34	+18	+14	−50
1966											
A	−33	−130	−18	+21	+24	−27	−10	+52	−40	0	−26
B	−26	+6	−21	+30	−19	−26	+34	−102	−4	+29	+44
C	+38	−72	−28	+54	−26	+12	−14	+4	+13	+6	+1
1967											
A	+80	−57	−14	−8	−14	−4	−26	+10	0	−26	+12
B	+32	+10	−38	−29	−36	−10	+22	+39	+6	−8	+11
C	+24	+2	+22	+4	−43	+7	+31	+16	+33	+33	+13
1968											
A	+3	−16	+34	+32	−8	−18	−8	−17	+23	+2	+21
B	−48	+114	+8	−18	+4	−13	+17	−7	−8	−28	−30
C	−57	+44	0	−10	−18	+41	+21	+22	+30	+49	−2
1969											
A	+47	−58	+22	−1	+83	−4	−22	−77	+30	+25	+30
B	+11	+56	+5	+7	−24	−14	+11	−71	−25	−1	−13
C	−3	+27	+3	+39	−6	+39	−6	+36	+12	−1	+6
1970											
A	+40	−57	+19	+10	+61	−6	−17	−71	+22	+12	−27
B	−59	+80	+9	−10	−16	−21	+11	−64	+45	−17	+1
C	+5	−25	+11	−15	+2	+11	+13	+20	+36	+6	+36